NASA TECHNICAL NOTE **NASA TN D-3706**

NASA TN D-3706

WEAR AND FRICTION OF VARIOUS POLYMER LAMINATES IN LIQUID NITROGEN AND IN LIQUID HYDROGEN

by Donald W. Wisander, Lawrence P. Ludwig, and Robert L. Johnson

Lewis Research Center
Cleveland, Ohio

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • NOVEMBER 1966

WEAR AND FRICTION OF VARIOUS POLYMER LAMINATES IN LIQUID NITROGEN AND IN LIQUID HYDROGEN

By Donald W. Wisander, Lawrence P. Ludwig, and Robert L. Johnson

Lewis Research Center
Cleveland, Ohio

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

For sale by the Clearinghouse for Federal Scientific and Technical Information
Springfield, Virginia 22151 – Price $1.00

WEAR AND FRICTION OF VARIOUS POLYMER LAMINATES IN LIQUID NITROGEN AND IN LIQUID HYDROGEN

by Donald W. Wisander, Lawrence P. Ludwig, and Robert L. Johnson

Lewis Research Center

SUMMARY

Wear and friction of polymer laminates were determined in liquid nitrogen and liquid hydrogen. Polymers included polytetrafluoroethylene (PTFE), phenol formaldehyde (phenolic), epoxy-formaldehyde (epoxy), and melamine formaldehyde (melamine); fabrics included glass, graphite, cotton, and nylon. Wear and friction experiments were conducted with a 3/16-inch-radius hemispherically-tipped polymer laminate rider sliding on the flat surface of a rotating 304-stainless-steel disk. The sliding velocity was maintained at 2300 feet per minute. The polymer laminate riders were under a 1000-gram load against the disk.

The results of the investivation indicate that a laminate of graphite fabric and phenolic resin is a potentially useful material for sliding contact in liquid nitrogen and that a laminate of glass fabric and PTFE resin is useful in liquid hydrogen. (The mechanical strengths of these materials were not evaluated.) Wear and friction of the laminates were appreciably higher in liquid hydrogen than in liquid nitrogen.

INTRODUCTION

Solid surfaces under sliding and rolling contact are used in mechanical devices employed in cryogenic industrial and aerospace applications (refs. 1 to 3). A common application is the turbopump used to transfer cryogenic fluids such as liquid nitrogen and liquid hydrogen. In this application, rolling element bearings and shaft seals operate submerged in the cryogenic fluids, which are poor lubricants; proper lubrication is therefore vital to bearing and seal performance and life.

Liquid nitrogen and liquid hydrogen are poor lubricants for two reasons:

(1) Low viscosity (one ten-thousandth to one-thousandth of that of SAE-30 oil at 100° F) results in a correspondingly low hydrodynamic load-carrying capacity.

(2) The chemical nature of these fluids prevents repair of worn surface oxide films, which play a vital role in boundary lubrication of metallic materials (ref. 1).

Cryogenic liquids, in general, fill only one of the various functions normally provided by a lubricant, that of cooling. Because of these physical and chemical properties of cryogenic fluids, the sliding and rolling surfaces should be either self-lubricating or protected by a solid-film lubricant. Friction and wear data for a number of self-lubricating materials and solid-film lubricants useful in liquid nitrogen and in liquid hydrogen are given in references 4 to 8.

The self-lubricating property of materials has been used successfully with cages of ball bearings operating in liquid nitrogen (ref. 9) and in liquid hydrogen (ref. 10). Data from references 9 and 10 show that self-lubricating glass-filled polytetrafluoroethylene (PTFE) cages of rolling-element bearings performed satisfactorily with less wear than various other cage materials. The data, however, indicated that the wear of filled PTFE cages is significant and that improved cage materials would be desirable.

Improvement in the wear life of polymers, such as PTFE and polyimide, have been made through the addition of various fillers (e.g., glass and copper) which increase mechanical strength and thermal conductivity (refs. 11 and 12). These fillers are usually in the form of fibers or powders. The use of fabrics as polymer strengtheners (polymer laminates) has not been evaluated for friction and wear in cryogenic environments. The potential usefulness of polymer laminates is indicated by the successful application of a polymer laminate as a bearing cage material at normal temperatures and by the useful mechanical strengths exhibited by glass fabric polymer laminates at cryogenic temperatures (ref. 13).

The objectives of this investigation were (1) to determine friction and wear properties of various polymers strengthened by fabric layers (polymer laminates) in liquid nitrogen and in liquid hydrogen and (2) to determine the effect of fabric material on friction and wear of polymer laminates. The resins used in the evaluation were PTFE, phenol formaldehyde (phenolic), melamine formaldehyde (melamine), and epoxy formaldehyde (epoxy); the fabrics used were cotton, graphite, glass, and nylon.

Filled PTFE (15 percent glass fiber, 5 percent graphite powder, and 80 percent PTFE) was selected as a basis of comparison because it is comparable with several materials successfully used in a cryogenic bearing cage. The reference material and the polymer laminates were evaluated in liquid hydrogen and in liquid nitrogen.

APPARATUS AND PROCEDURE

The apparatus used in this investigation is shown schematically in figure 1. The basic elements consisted of a hemispherically-tipped 3/16-inch-radius rider specimen

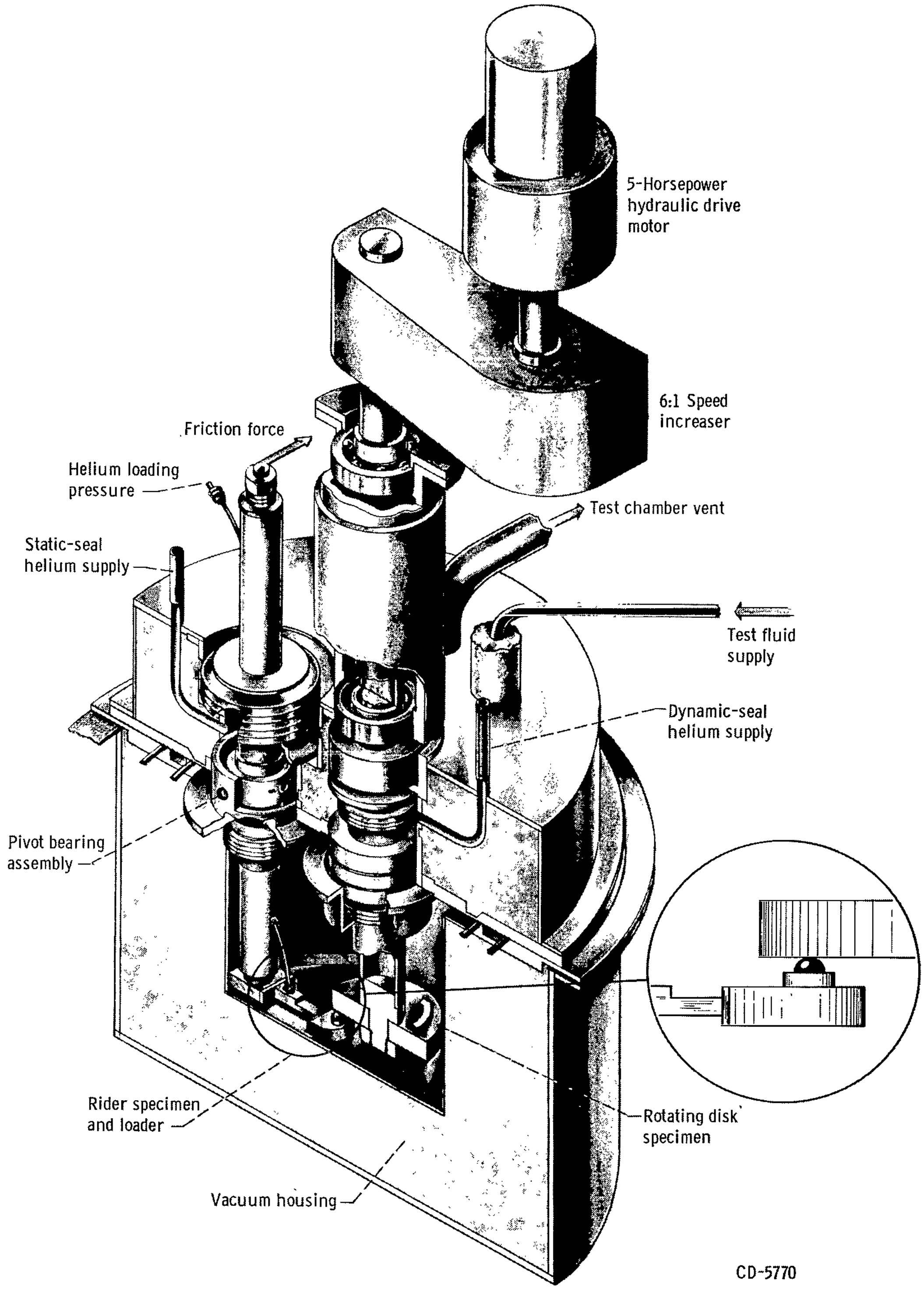


Figure 1. - Cryogenic friction apparatus.

held in sliding contact with the lower flat surface of a $2\frac{1}{2}$-inch-diameter rotating disk. The experiments were conducted with specimens completely submerged in liquid nitrogen or in liquid hydrogen. The drive shaft supporting the disk specimen was driven by a hydraulic motor through a 6:1 speed increaser and provided sliding velocities of 2300 feet per minute (4000 rpm) for the data reported herein. Two sets of helium-purged contact seals were used to prevent air leakage in and cryogenic liquid leakage out around the drive shaft.

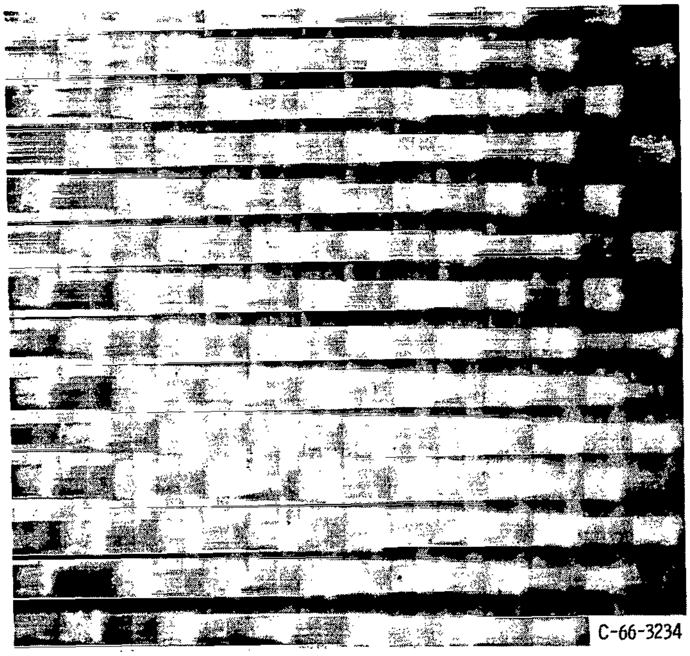
The rider specimen, supported by a pivoted arm and bellows assembly, was loaded to 1000 grams against the rotating disk specimen by a helium-pressurized piston assembly. Frictional force was measured by a load ring dynamometer mounted on the outside of the environmental chamber, which restrained the pivoted arm motion when sliding contact was induced.

The cryogenic fluid was transferred to the test chamber through a closed system. The storage vessel was pressurized to 4 pounds per square inch to transfer the liquid. The proper liquid level (about 2 in. above the disk) was maintained during the experiment by controlling the pressure in the storage vessel. The pressure in the test chamber was held at $1\frac{1}{2}$ pounds per square inch gage by a pressure relief valve in the vent line.

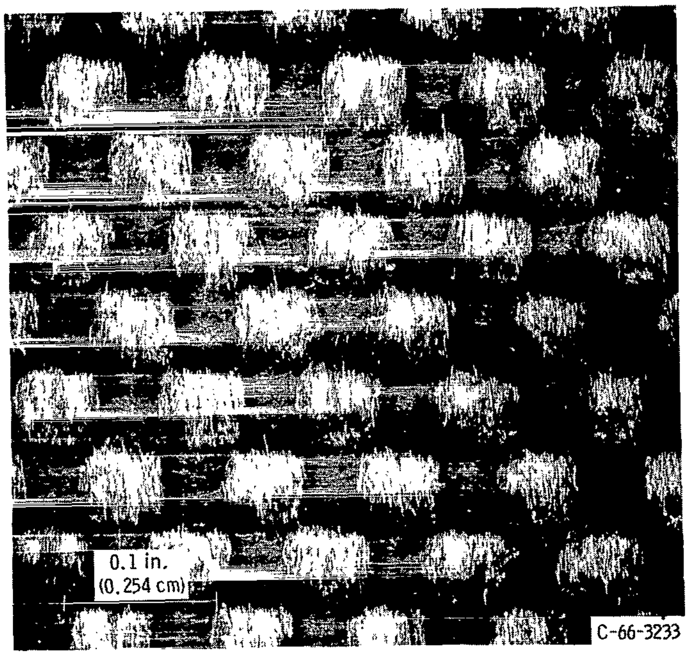
The test chamber was cleaned with ACS-certified acetone prior to each run. After cleaning, the test chamber was closed, purged 15 minutes with nitrogen or helium gas, and filled with operating liquid. When the test chamber was full, the drive motor was started and adjusted to the proper speed. After stabilization of the liquid level, the rider specimen was loaded against the disk. Frictional force was measured with a recording potentiometer used as a strain indicator. The duration of most runs was 1/2 hour. The wear of the rider specimen was determined by measuring the wear-scar diameter and calculating the wear volume.

The surfaces of the metal disk specimens were cleaned as follows: They were (a) electrochemically etched in a 1 part hydrochloric acid - 5 part water solution (Examination under a microscope and water wetting tests indicated that a current of 40 A at 15 V removed all traces of PTFE remaining from previous use.), (b) finish-ground to 4-8 rms; (c) scrubbed with moist levigated alumina, (d) washed in tap water, (e) washed in distilled water, (f) washed in 100 percent ethyl alcohol, and (g) dried and stored in a desiccator.

Plastic rider specimens were cleaned as follows: They were (a) washed and soaked with 100 percent ethyl alcohol, (b) vacuum dried at an absolute pressure of 10 millimeter of mercury for 24 hours (Dry nitrogen gas slightly above atmospheric pressure was introduced into the vacuum chamber after vacuum drying.), and stored in a desiccator for at least 48 hours before use.



(a) Glass fabric weave.



(b) Graphite fabric weave.

Figure 2. - Typical weave construction of fabrics used in polymer laminates.

MATERIALS

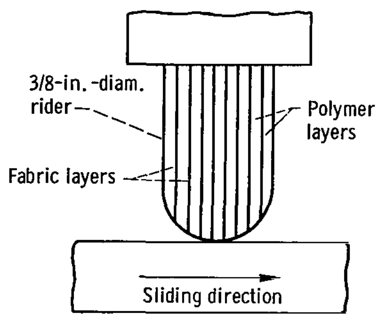
The materials evaluated (listed in table I) were laminated with alternate layers of fabric and polymer resin. Typical fabric (cloth) weaves are shown in figure 2. Usual construction of the laminate involved (a) coating or dipping the fabric with the resin binder, (b) stacking the required number of layers; and (c) curing at the required temperature and pressure. (A detailed description of laminate manufacturing methods is given in ref. 14.) Rider specimens of 3/8-inch diameter were machined from flat sheets of the laminates and had layers of fabric and resin orientated perpendicular to the sliding direction, as shown in figure 3.

TABLE I. - POLYMER LAMINATE MATERIAL INVESTIGATED

Polymer laminate		Fabric threads per inch	NEMA[a] grade	Ultimate tensile strength, psi, at -		
Fabric	Resin			Room temperature	-320° F	-423° F
Glass	Melamine formaldehyde	23	G-5	55×10^3	75×10^3	110×10^3
	Epoxy formaldehyde	41	G-11	45	------	70
	Phenol formaldehyde	70	G-3	50	------	70
	Polytetrafluoroethylene	41	----	------	------	-------
Graphite	Phenol formaldehyde	15	----	------	------	-------
	Polytetrafluoroethylene	13	----	------	------	-------
Cotton	Phenol formaldehyde	81	L	------	------	-------
Nylon	Phenol formaldehyde	71	N-1	------	------	-------

[a]National Electrical Manufacturer Association.

(a) Enlarged view of laminate showing layer construction.



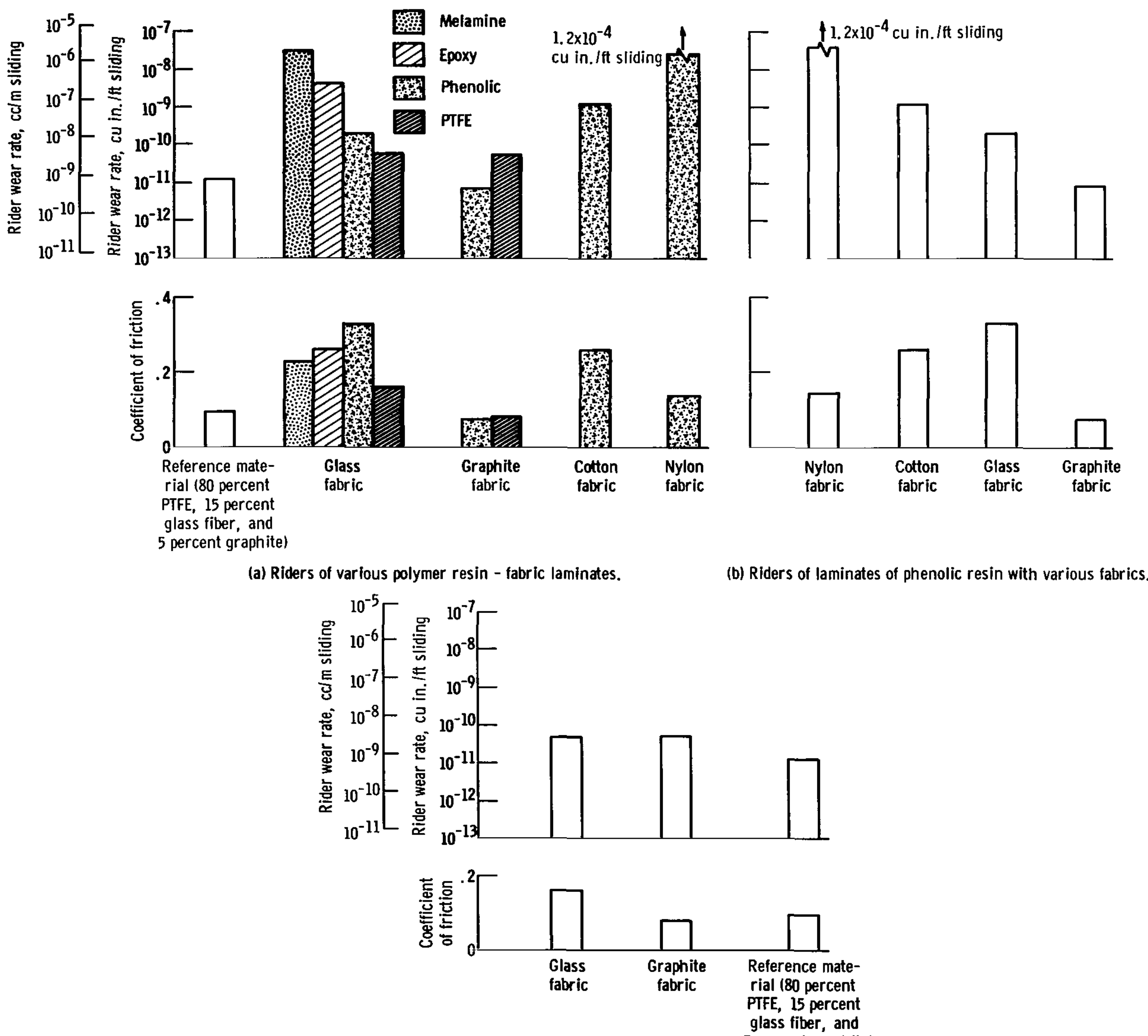
(b) Orientation of fabric layers perpendicular to sliding direction.

Figure 3. - Typical polymer-laminate rider construction.

RESULTS AND DISCUSSION

Liquid-Nitrogen Environment

Figure 4(a) shows the wear and friction results for various polymer laminate riders sliding against a 304-stainless-steel disk submerged in liquid nitrogen. The results indicate that the laminate of graphite fabric and phenolic resin is the only material of those investigated which has wear and friction comparable with that of the reference material (80 percent PTFE, 15 percent glass, and 5 percent graphite). (The laminate of graphite

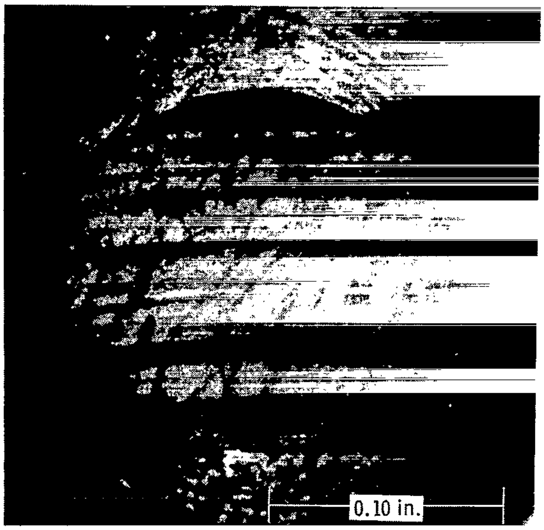


(a) Riders of various polymer resin - fabric laminates.

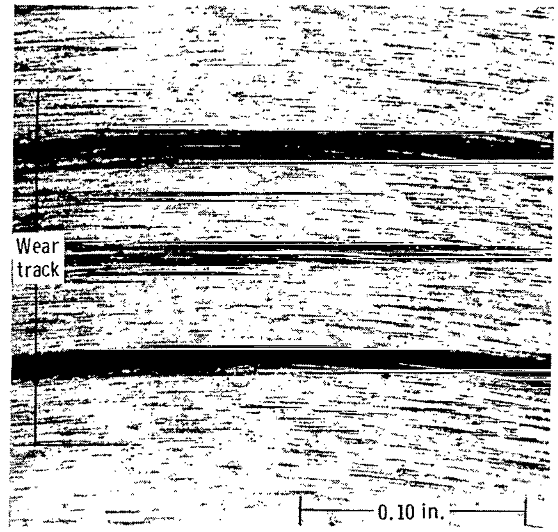
(b) Riders of laminates of phenolic resin with various fabrics.

(c) Riders of laminates of PTFE resin with various fabrics.

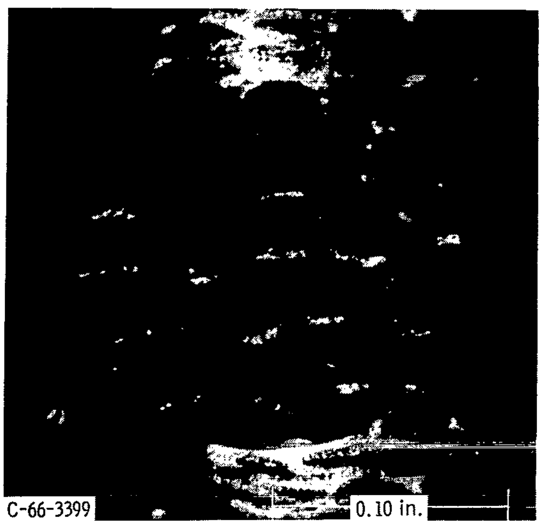
Figure 4. - Wear and friction of rider sliding on 304-stainless-steel disks in liquid nitrogen. Sliding velocity, 2300 feet per minute; load, 1000 grams; duration, 1/2 hour.



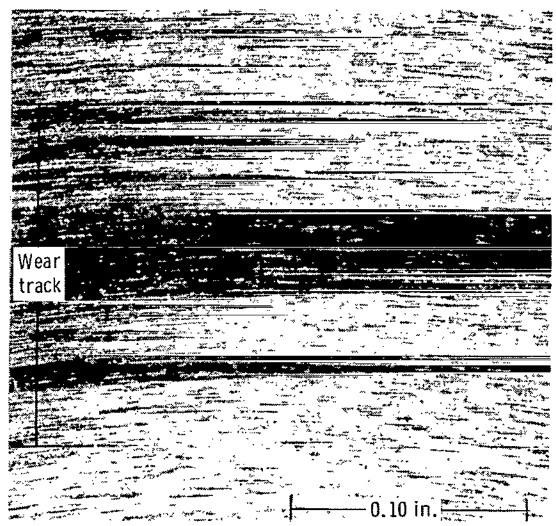
(a) Graphite fabric and phenolic resin rider.



(b) Wear track on 304-stainless-steel disk of graphite fabric and phenolic resin rider.

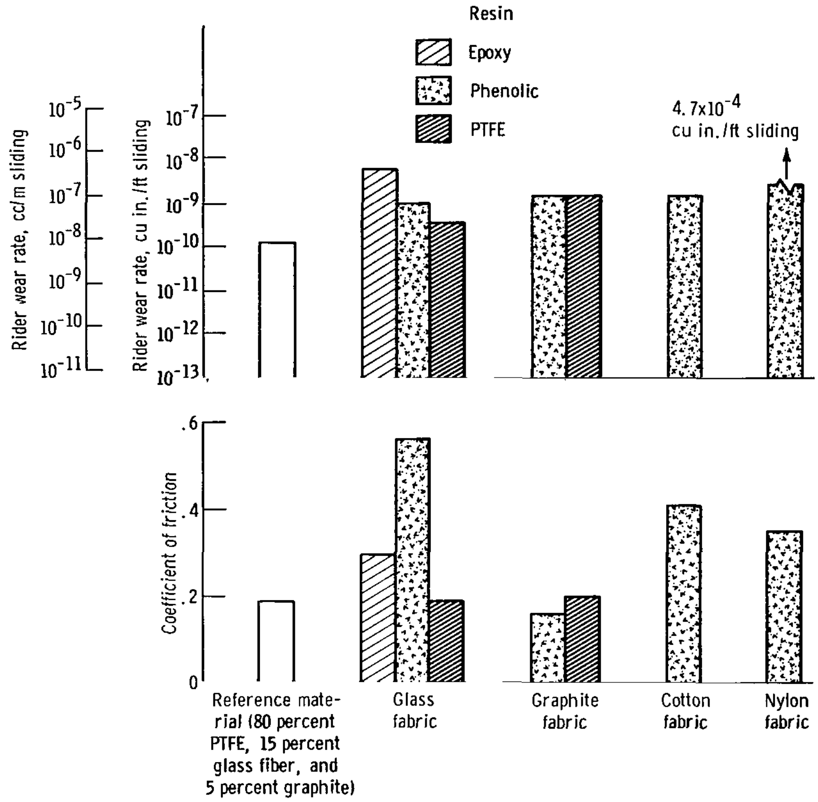


(c) Graphite fabric and PTFE resin rider.

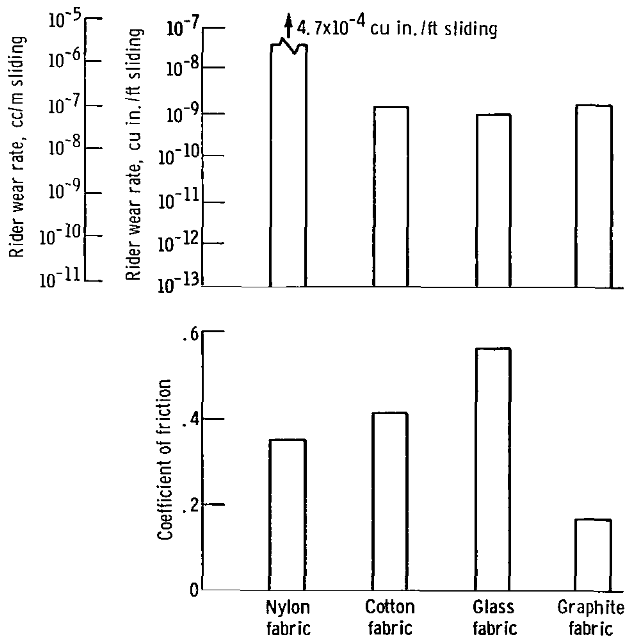


(d) Wear track on 304-stainless-steel disk of graphite fabric and PTFE resin rider.

Figure 5. - Rider wear scar and disk wear track of two plastic laminate - metal combinations after sliding in liquid hydrogen. Sliding velocity, 2300 feet per minute; load, 1000 grams; duration, 1 hour.



(a) Riders of various polymer laminates.



(b) Riders of laminates of phenolic resins with various fabrics.

Figure 6. - Wear and friction of riders sliding on 304-stainless-steel disks in liquid hydrogen. Sliding velocity, 2300 feet per minute; load, 1000 grams; duration, 1/2 hour.

fabric and phenolic resin has lower mechanical strength than the reference material.) As mentioned previously, glass-fiber-filled PTFE cages of rolling-element bearings performed satisfactorily in liquid nitrogen (ref. 9) and in liquid hydrogen (ref. 10). The other materials showing potential usefulness for liquid-nitrogen application based on friction and wear data are laminates of graphite fabric and PTFE resin and of glass fabric and PTFE resin (fig. 4(a)).

Figure 4(b) shows a comparison of wear and friction on laminates of phenolic resins with different fabrics. Laminates of graphite fabric and phenolic resin showed lower wear and friction than laminates of phenolic resin with glass, cotton, or nylon fabrics. Further evidence of the potential usefulness of graphite fabric is found in the comparison of the laminates of graphite fabric - PTFE resin and glass fabric - PTFE resin (fig. 4(c)). Laminates of graphite fabric and PTFE resin had the lowest friction coefficient; the wear rates were comparable. The reference material wear rate was lower than that of the graphite fabric laminate. Figure 5 shows typical rider wear scars and corresponding disk wear tracks for laminates of graphite fabric and phenolic resin (figs. 5(a) and (b)) and of graphite fabric and PTFE resin (figs. 5(c) and (d)) sliding on 304-stainless-steel disks. The perpendicular fabric orientation is evident.

Liquid-Hydrogen Environment

Figure 6(a) shows the wear and friction results for various polymer laminate riders sliding ageinst a 304-stainless-steel disk submerged in liquid hydrogen. The results show that the reference material had the lowest wear rate of all the polymer laminates evaluated. The laminate of graphite fabric and phenolic resin had the lowest friction coefficient in hydrogen but the wear rate was 10 times greater than that for the reference material. The friction and wear of the glass fabric PTFE laminate are comparable to that of the reference material.

Figure 6(b) is a comparison of laminates of phenolic resin with different fabrics. The laminate of graphite fabric and phenolic resin had the lowest coefficient of friction; however, the wear rate was comparable with those of the laminates of cotton fabric and phenolic resin and of glass fabric and phenolic resin.

Comparison of Results in Liquid Nitrogen and in Liquid Hydrogen

Laminates of glass fabric and PTFE resin, graphite fabric and PTFE resin, and graphite fabric and phenolic resin showed wear and friction results comparable with the reference material in liquid nitrogen and in liquid hydrogen. For comparison, the data are repeated in figure 7. Except for the laminate of glass fabric and PTFE resin, the coefficient of friction in liquid nitrogen is about one-half that in liquid hydrogen, and the

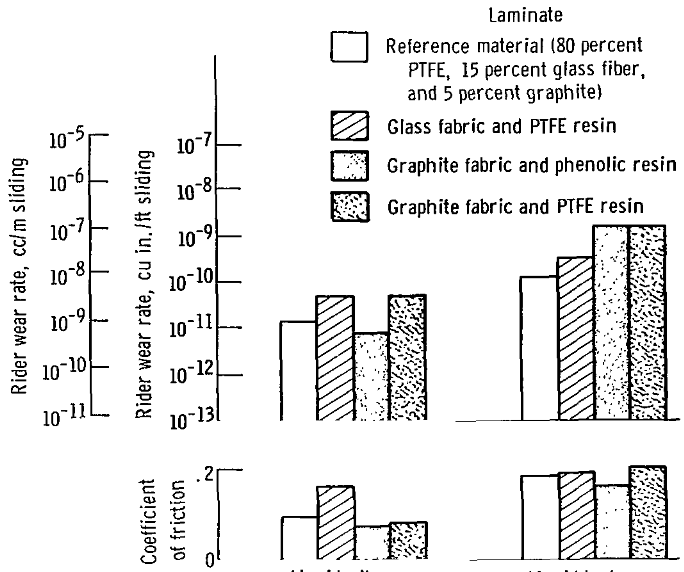


Figure 7. - Comparison of polymer laminate wear and friction, in liquid nitrogen and in liquid hydrogen.

wear rate in liquid nitrogen is about one-tenth that in liquid hydrogen.

SUMMARY OF RESULTS

Wear and friction studies on polymer laminate riders sliding against a 304-stainless-steel disk in liquid nitrogen and in liquid hydrogen revealed the following:

1. Wear and friction of the laminate riders were appreciably less in liquid nitrogen than in liquid hydrogen.

2. The laminate of graphite fabric and phenol formaldehyde resin is potentially useful for sliding contact in liquid nitrogen since wear and friction were comparable with those of the reference material (80 percent polytetrafluoroethylene (PTFE), 15 percent glass fiber, and 5 percent graphite). (This laminate of graphite fabric and phenol formaldehyde resin has lower mechanical strength than the reference material.)

3. In liquid hydrogen, the laminate of glass fiber and PTFE resin showed wear and friction properties comparable with those of the reference material.

4. All laminate combinations with phenol formaldehyde resins showed high friction values with the exception of the graphite fabric - phenol formaldehyde resin combination.

In general, PTFE- and graphite-containing laminates had useful friction and wear performance.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, August 4, 1966,
129-03-13-01-22.

REFERENCES

1. Bisson, Edmond E.; and Anderson, William J.: Advanced Bearing Technology. NASA SP-38, 1964.
2. Scott, Russell B.: Cryogenic Engineering. D. VanNostrand Co., Inc., 1959.
3. Powers, J. V., Jr.: A Rotational Sealing Coupling for Cryogenic Uses. Advances in Cryogenic Engineering. K. D. Timmerhaus, ed., vol. 10, Plenum Press, Inc., 1965, sections A-L, pp. 458-463.
4. Wisander, D. W.; Hady, W. F.; and Johnson, R. L.: Friction Studies of Various Materials in Liquid Nitrogen. NACA TN 4211, 1958.
5. Wisander, D. W.; and Johnson, R. L.: A Solid Film Lubricant Composition for Use at High Sliding Velocities in Liquid Nitrogen. ASLE Trans., vol. 3, no. 2, 1960, pp. 225-231.
6. Wisander, D. W.; and Johnson, R. L.: Wear and Friction in Liquid Nitrogen with Austenitic Stainless Steel Having Various Surface Coatings. Advances in Cryogenic Engineering, K. D. Timmerhaus, ed., vol. 4, Plenum Press, Inc., 1960, pp. 71-83.
7. Wisander, Donald W.; Maley, Charles E.; and Johnson, Robert L.: Wear and Friction of Filled Polytetrafluoroethylene Compositions in Liquid Nitrogen. ASLE Trans., vol. 2, no. 1, Apr. 1959, pp. 58-66.
8. Wisander, D. W.; and Johnson, R. L.: Wear and Friction of Impregnated Carbon Seal Materials in Liquid Nitrogen and Hydrogen. Advances in Cryogenic Engineering, K. D. Timmerhaus, ed., vol. 6, Plenum Press, Inc., 1961, pp. 210-218.
9. Wilson, W. A.; Martin, K. B.; Brennan, J. A.; and Birmingham, B. W.: Evaluation of Ball Bearing Separator Materials Operating Submerged in Liquid Nitrogen. ASLE Trans., vol. 4, no. 1, Apr. 1961, pp. 50-58.

10. Scibbe, Herbert W.; and Anderson, William J.: Evaluation of Ball-Bearing Performance in Liquid Hydrogen at DN Values to 1.6 Million. ASLE Trans., vol. 5, no. 1, Apr. 1962, pp. 220-232.

11. Mitchell, D. C.; and Pratt, G.: Friction, Wear and Physical Properties of Some Filled P.T.F.E. Bearing Materials. Conference on Lubrication and Wear (London). Institution of Mechanical Engineers, 1957, pp. 416-424.

12. Buckley, Donald H.: Friction and Wear Characteristics of Polyimide and Filled Polyimide Compositions in Vacuum (10^{-10} mm Hg). NASA TN D-3261, 1966.

13. Chamberlain, D. W.: Mechanical Properties Testing of Plastic Laminate Materials Down to 20° K. Advances in Cryogenic Engineering, K. D. Timmerhaus, ed., vol. 10, Plenum Press, Inc., 1965, Sections A-L, pp. 117-125.

14. Duffin, Daniel J.: Laminated Plastics. Reinhold Publ. Corp., 1958.

"The aeronautical and space activities of the United States shall be conducted so as to contribute . . . to the expansion of human knowledge of phenomena in the atmosphere and space. The Administration shall provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof."

—NATIONAL AERONAUTICS AND SPACE ACT OF 1958

NASA SCIENTIFIC AND TECHNICAL PUBLICATIONS

TECHNICAL REPORTS: Scientific and technical information considered important, complete, and a lasting contribution to existing knowledge.

TECHNICAL NOTES: Information less broad in scope but nevertheless of importance as a contribution to existing knowledge.

TECHNICAL MEMORANDUMS: Information receiving limited distribution because of preliminary data, security classification, or other reasons.

CONTRACTOR REPORTS: Technical information generated in connection with a NASA contract or grant and released under NASA auspices.

TECHNICAL TRANSLATIONS: Information published in a foreign language considered to merit NASA distribution in English.

TECHNICAL REPRINTS: Information derived from NASA activities and initially published in the form of journal articles.

SPECIAL PUBLICATIONS: Information derived from or of value to NASA activities but not necessarily reporting the results of individual NASA-programmed scientific efforts. Publications include conference proceedings, monographs, data compilations, handbooks, sourcebooks, and special bibliographies.

Details on the availability of these publications may be obtained from:

SCIENTIFIC AND TECHNICAL INFORMATION DIVISION

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Washington, D.C. 20546